REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	10/16/02	Final Technical Report, 1/16/02 to 10/16/03

4. TITLE AND SUBTITLE
Front-End Prototype for JTRS System

5. FUNDING NUMBERS
N00014-02-C-0006

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10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
"Distribution Statement A. Approved for Public Release; distribution unlimited."

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Two superconducting filters were designed, developed, and delivered for integration into a high performance wide-band receiver. A high temperature superconducting (HTS) pre-selector bandpass was completed, and an HTS notch filter was completed. These filters provide both high out-of-band rejection (better than 100 dB) and low noise figure (better than 0.5 dB center band). .

14. SUBJECT TERMS
Superconducting filters, pre-selector bandpass, HTS notch filter

15. NUMBER OF PAGES
8

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	SAR

Executive Summary

Two superconducting filters were designed, developed, and delivered for integration into a high performance wide-band receiver. A high temperature superconducting (HTS) pre-selector bandpass was completed, and an HTS notch filter was completed. These filters provide both high out-of-band rejection (better than 100 dB) and low noise figure (better than 0.5 dB center band). All Year 1 and Year 2 tasks were successfully completed. Due to a lack of funding, the Year 3 tasks were descoped.

Technical Performance

During the course of the contract, we worked with Hypres and the Navy to better defined the desired specifications for these two filters. The following targets were used as goals for this filter development task:

1) We will design a bandpass filter that covers the range from 390 – 400 MHz. Our target rejection is better than 50 dBc @ 408 MHz, and a better than 80 dBc ultimate out-of-band rejection
2) We will design a notch filter centered at around 393 MHz with a target notch depth (rejection) of 50 dBc, and with a rejection bandwidth of around 5 kHz. It will be well-match over the passband from 390-400 MHz.
3) We will design an LNA with a gain of approximately 15 dB and a flatness of 0.5 dB across the 10 MHz band.

Filters were designed using the above criteria. We worked with Hypres to design a filter package that met their thermal and electrical interface requirements. The filters were then assembled in those packages and tested. Note that we also met the desire of ONR to make the packages separate, so that the bandpass filter could be used with or without the notch.

We will outline the measured performance of the filters and compare the achieved results with the goals of the program. In Figure 1, we show the performance of the notch/bandpass combination. First, the bandpass clearly meets the desired frequency range of 390-400 MHz. The return loss is well matched across the whole passband. The markers show that the measured rejection at 408 MHz was 50.08 dBc, which meets the desired goal of 50 dBc. Note that dBc is the difference in transmission at a particular frequency referenced to the passband. In Figure 2, we show the performance of the notch/bandpass combination over a wide range (225 MHz to 500 MHz). The measured data show that we achieved ultimate out-of-band rejection exceeding 100 dBc. Therefore, we greatly exceeded the goal of 80 dBc.

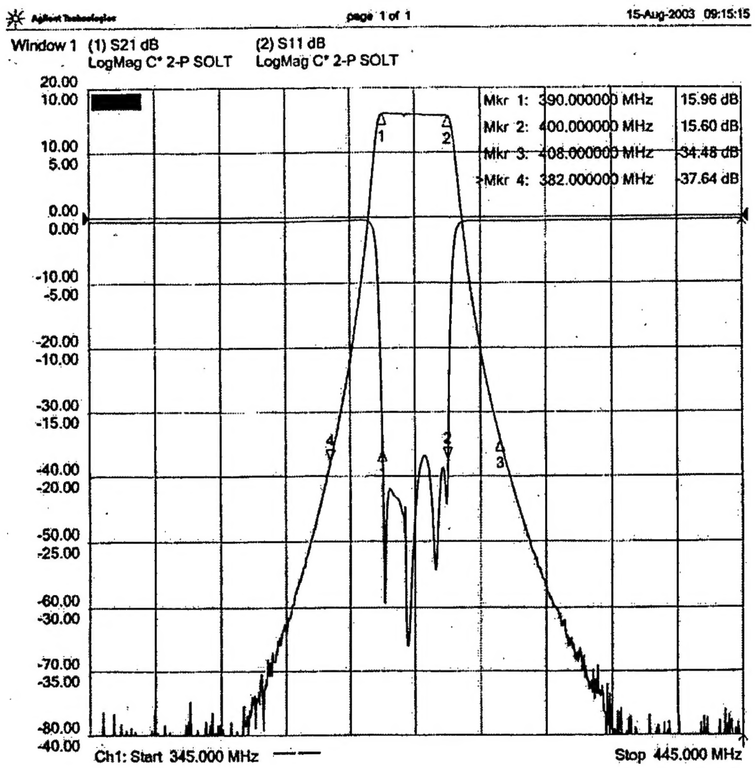

Figure 1: Bandpass response with rejection points (met 50dBc goal)

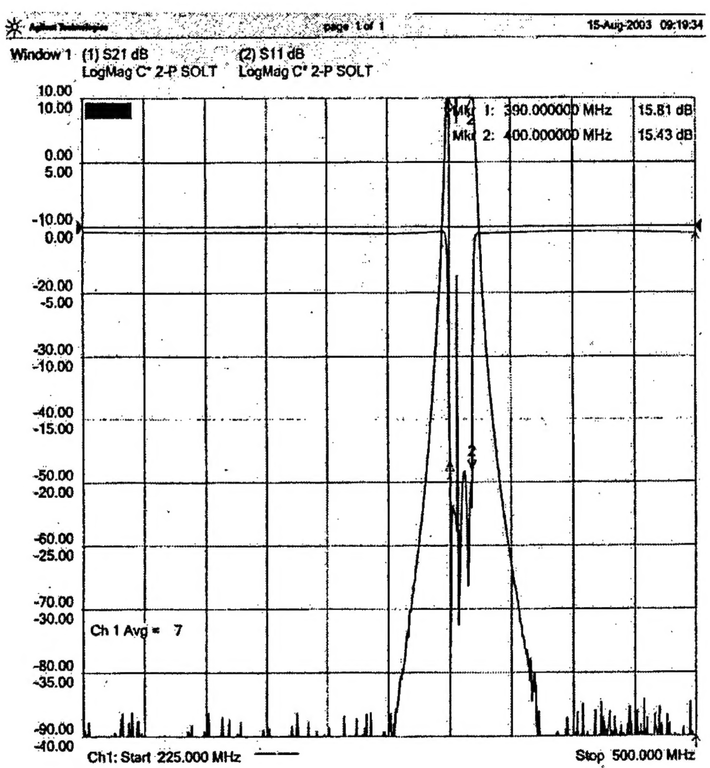

Figure 2: Wideband response (> 80dBc goal)

In Figure 3, we show the measured response of the notch. The goal was to achieve 50 dBc over a 5 kHz width. Following the suggestion of ONR, we used a notch design that was not our first choice. However, we agreed to use a best-effort approach. While we fell slightly short of the desired goal, we exceeded our own expectations with this design. The placement of the poles in the notch needed to be so precise, that we had to laser trim the poles to the exact location. We were able to achieve 50 dBc rejection in the center of the notch, but we were only able to achieve a notch depth of 44 dBc over the 5 kHz band. This was mainly due to small remaining inaccuracy (<1kHz) in one of the pole frequencies after final assembly.

Figure 4, shows the response of the notch within the bandpass range. The data shows that the notch is well-matched over the full 10 MHz band and does not adversely affect the desired signal. In Figure 5, we show the response of the notch only over the full 225-400 MHz band. While we did not commit that we could match the notch over the full range given the remaining funding, we did commit to measure the response over the full band. The good news is that the notch turned out to be well-matched across the full range without the need of another iteration. Note that the notch is so narrow with respect to the range that there are not enough points in the plot the fully outline the notch. This is why the dip in the S21 is not seen.

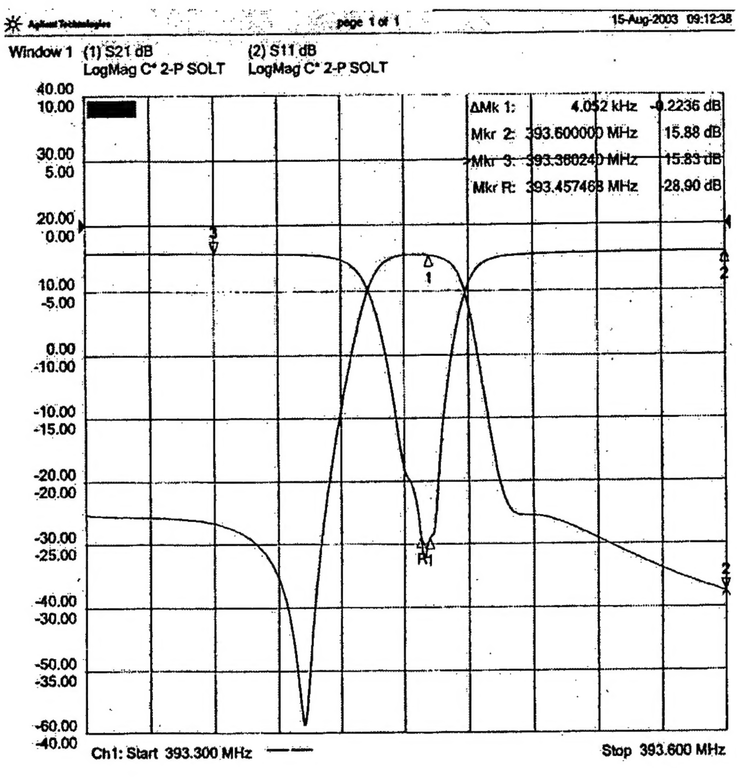

Figure 3: Notch response (50dBc center, 44dBc over 5kHz band)

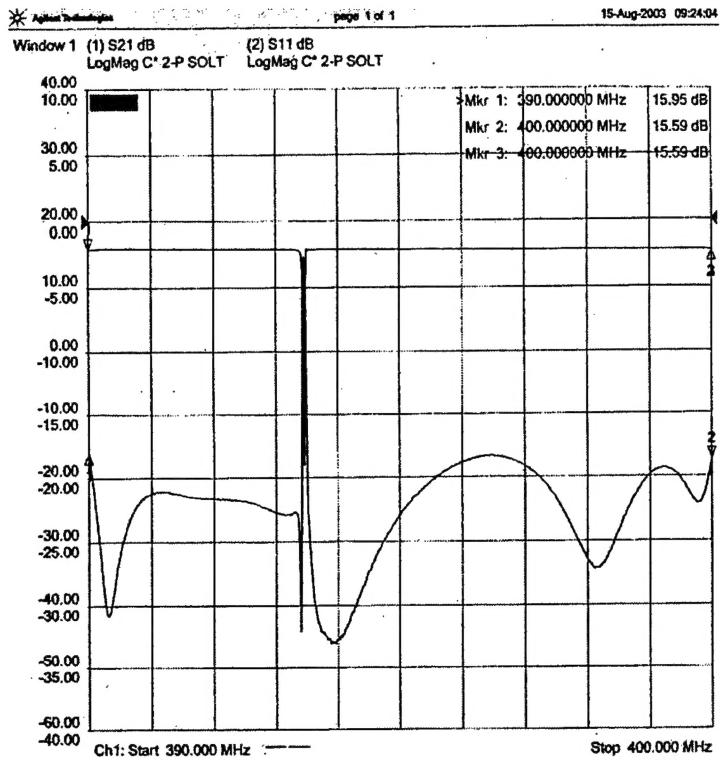

Figure 4: Notch response within 10MHz passband

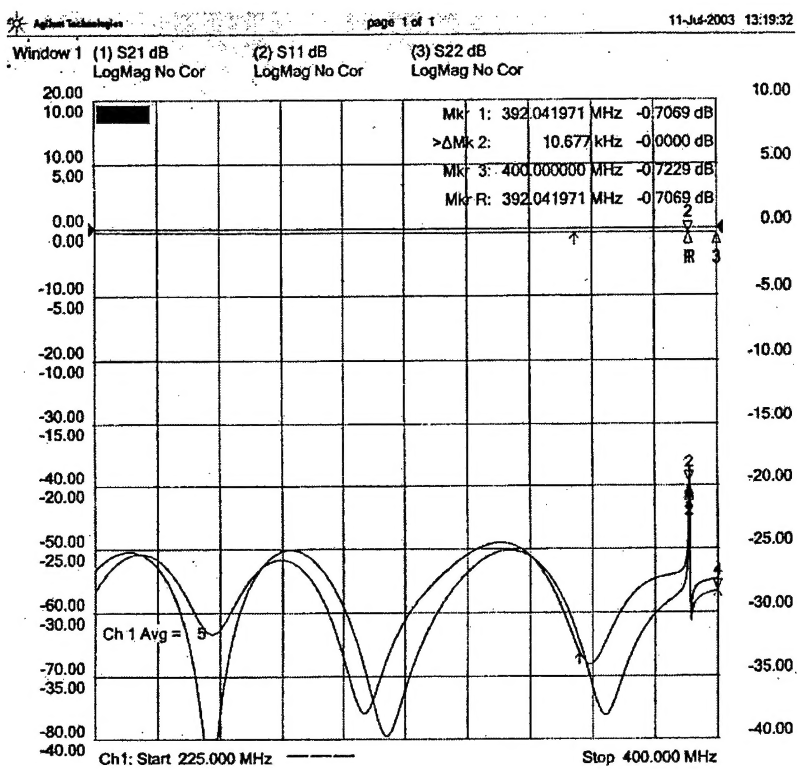

Figure 5: Notch-only response over 225-400 MHz range

In Figure 6, we show the measured response for the gain of the notch/bandpass combination. As can be seen in the plot, the gain is around 15.8 dB and the flatness is 0.42 dB. This meets the goals of around 15 dB in gain and flatness less than 0.5 dB. Note that the drop close to the middle of the band is from the notch. Finally, while not a goal in the program, we measured the Noise Figure. Figure 7 shows that we were able to achieve a Noise Figure below 0.5 dB, in the center of the band, for the notch/bandpass/LNA packages and all associated input and output RF cables. This low Noise Figure is quite an achievement for these high performance filters.

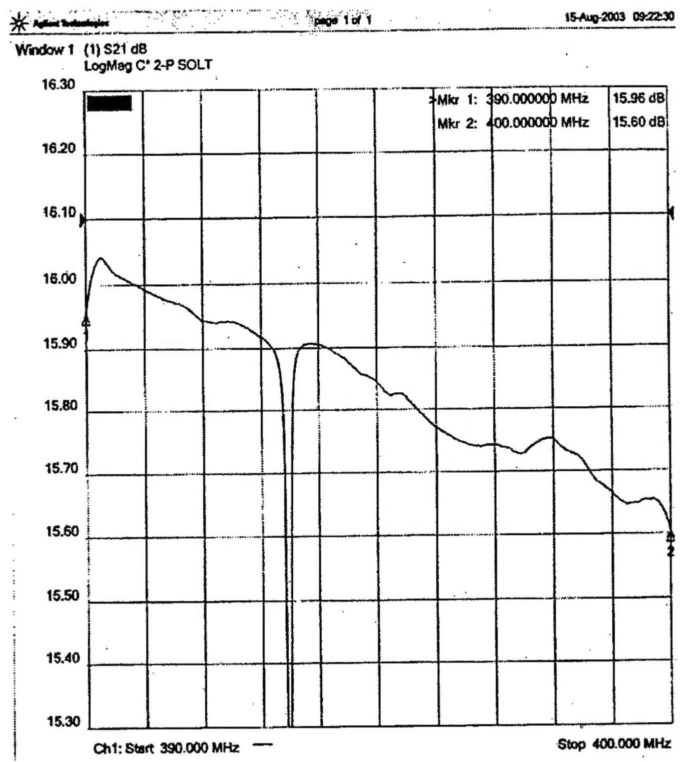

Figure 6: Gain flatness below 0.5 dB

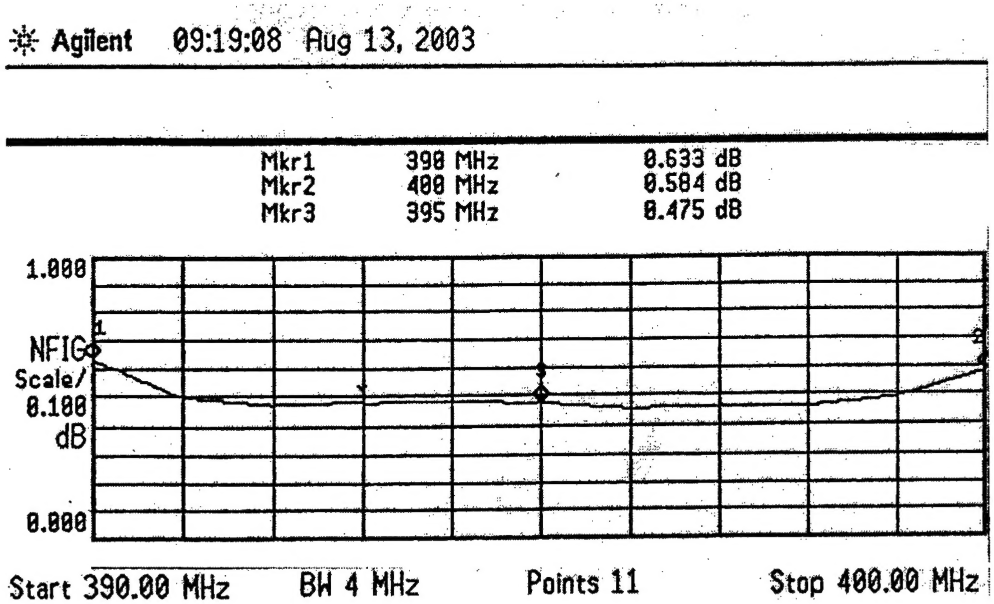

Figure 7: Noise Figure for the delivered 2-filter system

Summary by Task of project accomplishments:

1. Design and development of two different filters for needed frequency band each (has to be specified). Preliminary frequency range is 225-400 MHz and bandwidth about 10 MHz. The out of band rejection has to be at least 80dB. Design has to be optimized for exact temperature on the mounting plate (which is depend on cooler specification and system load on the stage).

Accomplished, see data in this report

2. Optimization of the LNA design for needed frequency range and minimal bias to minimize thermal load on the cryocooler. Gain of the each amplifier has to be not less than 15dB with the flatness in the band less than 0.5dB.

Accomplished, see data in this report

3. Design compact Diplexer/Filter/LNA package to fit in the limiting area on the 77K stage of the COTS (or another chosen cryocooler) and minimize weight to reduce cool down time. Filter will be pre-tuned and could be installed on the system without any additional tuning.

Accomplished. The filter/LNA package was delivered and does not require additional tuning.

4. Modeling and design of the analog part of the system, cryogenic interconnections (RF and DC wiring), vacuum compatibility and heat distribution.

Accomplished.

5. Assisting HYPRES in whole system cryogenic design: cryogenic properties, magnetic shielding, wiring, thermal load distribution, RF property of the packaging and interconnections.

Accomplished.

Note: Year 3 tasks were descoped from the contract due to lack of funding.